IONIZATION SOURCE UTILIZING A JET DISTURBER IN COMBINATION WITH AN ION FUNNEL AND METHOD OF OPERATION

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Government support under Contract DE-AC06-76RLO 1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

CROSS REFERENCE TO RELATED APPLICATIONS

Not Applicable

FIELD OF THE INVENTION

The present invention relates generally to a method and apparatus for directing or focusing dispersed charged particles into a low pressure apparatus. More specifically, the invention utilizes a jet disturber used in combination with an ion funnel to focus ions and other charged particles generated at or near atmospheric pressure into a relatively low pressure region, which allows increased conductance of ions and other charged particles into the device. The invention may further make use of a multi-capillary inlet to further enhance the conductance of such charged particles.

BACKGROUND OF THE INVENTION

A great variety of scientific inquiry is confronted with the challenge of identifying the atomic structure or composition of particular substances. To assist in this identification, a variety of schemes have arisen which require the ionization of the particular substances of interest. Many of these analytical techniques, as well as the other industrial uses of charged particles, are carried out under conditions of high vacuum. However, many ion sources operate at or near atmospheric pressures. Thus, those skilled in the art are continually confronted with challenges associated with transporting ions and other charged particles generated at atmospheric or near atmospheric pressures into regions maintained under high vacuum.

An illustrative example of this general problem is presented in the use of electrospray ionization when combined with mass spectrometry as an analytical technique. Electrospray ion sources (which broadly includes, but is not limited to, nano electrosprays conventional electrosprays, microelectrospray, and nebulizing gas assisted electrospray) are widely used with mass spectrometry for sample analysis, for example in biological research. For m/z analysis, ions are typically created at atmospheric pressure by the electrospray ion source and are then transported to the high vacuum region of a mass spectrometer through a capillary inlet that penetrates the first chamber of the mass spectrometer. A differential pumping system involving several stages for stepwise pressure reduction is commonly used to achieve the vacuum conditions conventionally utilized in m/z analysis within the mass spectrometer, and the major design issues are generally related to optimizing overall ion transmission efficiencies.

Improved transmission efficiencies in the intermediate vacuum stages have been achieved by using the recently developed RF ion funnel at higher interface pressures (~1 to 10 Torr) and RF multi-pole ion guides with buffer gas cooling at lower interface pressures as more fully described in Shaffer, S. A.; Tang, K.; Anderson, G. A.; Prior, D. C.; Udseth, H. R.; Smith, R. D., *Rapid Commun. Mass Spectrom.* 1997, 11, 1813–1817; Shaffer, S. A.; Prior, D. C.; Anderson, G. A.; Udseth, H. R. and Smith, R. D. *Anal. Chem.* 1998, 70, 4111–4119; and Douglas, D. J.; French, J. B., *J. Am. Soc. Mass Spectrom.* 1992, 3, 398–408, and U.S. Pat. No. 6,107,628 entitled Method and Apparatus for Directing Ions and other Charged Particles Generated at Near Atmospheric Pressures into a Region under Vacuum, the entire contents of each of which are herein incorporated into this specification by this reference.

In co-pending U.S. patent application Ser. No. 09/860,727, filed May 18, 2001,

IMPROVED IONIZATION SOURCE UTILIZING A MULTI-CAPILLARY INLET AND METHOD OF OPERATION the entire contents of which are incorporated herein by this reference, a new interface having higher ion transmission efficiency compared to conventional interface designs is described. This interface, known as a multicapillary inlet, uses an array of capillaries to increase the gas throughput (i.e. the ion transmission) without sacrificing droplet desolvation efficiency and an electro-dynamic ion funnel for ion focusing into the next vacuum stage. To maintain the operating pressure of the ion funnel constant with the multi capillary inlet, the pumping for the first chamber (ion funnel chamber) is typically increased proportional to the conductance increase of the multicapillary inlet. It has been found that the directed gas stream from the larger conductance inlet was not completely dispersed, but retained some directed flow to the exit of the ion funnel. When the gas molecules with entrained ions enter into the first vacuum stage, the gas experiences an adiabatic expansion and forms a free jet. The expansion is surrounded by a concentric barrel shock and terminated by a perpendicular shock known as the Mach disc. In the expansion region, the gas molecules move in straight streamlines originating in the inlet. The region downstream of the Mach disc is known to have complex behavior. Far away from the inlet, the gas molecules move at random. There is a transition region where the directed motion changes into random motion in the region downstream of the Mach disc. In the ion funnel interface with the multi-capillary inlet, the transition region extends beyond the bottom of the ion funnel, and thus more gas is transferred to the second vacuum stage by the directed flow than with a single capillary inlet having a smaller conductance. Therefore, the pumping requirement in the second vacuum stage increases with the increase of the number of capillaries even though the ion funnel chamber is operated at the same pressure. Thus, an even higher vacuum pumping speed is required in the first stage (the ion funnel chamber) to maintain the second vacuum stage pressure in an acceptable range.

Thus, there exists a need for methods and apparatus that allow a reduction in the required pumping speed.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention in one of its aspects to provide a method for providing an ion or charged particle source in a pressure region at near atmospheric pressures. As used herein, "near atmospheric" pressures are defined as between 10^{-1} millibar and 1 bar. Also as used herein, the charged particles are defined as being smaller than one billion AMUs. The focusing of the present invention is accomplished by providing an apparatus, hereinafter referred to as a "jet disturber", which is positioned within an ion funnel. Most generally, a jet disturber may be any form